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Review Article

Effects of Aberrations on Objective and Subjective Measurements Following Refractive Surgery

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Received: June 22, 2022; **Published:** July 28, 2022

Abstract

The given review is to primarily address the influence of high order aberrations in refractive surgery outcomes regarding objective and subjective types of measurement. Additionally, there is going to be reference to how Wavefront-Optimized (WFO) ablations and Wavefront-guided ablations (WFG) affect both the final refractive result and the quality of vision. Standard Lasik is known to induce high-order aberrations, resulting in reduced visual performance, diminished subjective visual functioning as well as decreased quality of life related to vision. Therefore, Wavefront-optimised (WFO) ablations and Wavefront- guided ablations (WFG) have been recruited to deal with this problem. On the other hand, smile (small-incision lenticule extraction) as another introduced refractive surgery method constitutes an alternative suggestion. This literature review highlights recent developments in this field. Thus, considering the above parameters there are going to be suggestions regarding the selection of the optimum procedure.

Keywords: *Lasik, Wavefront-Optimized (WFO); Wavefront Guided (WFG); High-Order Aberrations (HOAs); Hartmann-Shack; Tscherning; Smile (Small-Incision Lenticule Extraction); i-Design; QoV (The Quality of Vision Questionnaire)*

Abbreviations

WFO: Wavefront-Optimized; WFG: Wavefront-Guided; HOAs: High-Order Aberrations; SA: Spherical Aberrations; RMS: Root Mean Square; PSF: Point Spread Function; MTF: Modulation Transfer Function; PRK: Photorefractive Keratectomy; LASIK: Laser *In Situ* Keratomileusis; SMILE: (Small-Incision Lenticule Extraction); i-Design; RSVP: The Refractive Status and Vision Profile; PROWL: The Patient-Reported Outcomes with Laser *In Situ* Keratomileusis; QoV: The Quality of Vision Questionnaire

Introduction

The quality of vision is of crucial significance in the outcome of the refractive surgery [1-4]. High order aberrations (HOAs) mainly spherical aberrations and coma, generate the most intense visual disturbances, along with the greatest visual dissatisfaction with the vision following a refractive surgery. This is due to the fact that apart from the common types of refractive error, that is, myopia, hypermetropia and astigmatism, there are also high order aberrations which cannot be corrected with the use of conventional refractive surgery [5-8]. The cause of the emergence of aberrations is the presence of imperfections on the surface of the cornea, which prevent the light from perfectly focusing on the retina [9]. The various imperfections in the optics of the eye, particularly in the crystalline lens and the cornea, lead to deviations from the ideal wavefront, which is supposed to be flat. This means that light pervading to the flat perfect optical system converges at a point on the retina and returns behind the convergence point, leaving the eye with a flat wavefront. However, given that the eye does not constitute a perfect optical system, it is not flat [10]. Aberrations in general are divided into LOAs (90%) and HOAs which are described with different Zernicke polynomials. Each polynomial expresses a finite number of terms, made up of variables and constants. Therefore, each individual Zernicke polynomial relates to a different type of visual aberration and introduces a separate type of blur in the image of the retina. Zernicke polynomials are used to decompose the wavefront data into different orders that describe one or more terms. Thus, a pyramid of polynomials is created. Zernicke polynomial constitute a combination of functions that describe wavefront mathematically [10]. Second order terms of defocus and astigmatism are addressed by the manifest refraction. Spherical aberrations (SA) are attributed to greater inclination of light rays in the periphery of the refractive surfaces of the eye in relation to the paraxial or central rays [1]. The asphericity degree of the cornea can be expressed as an asphericity quotient, named Q value. The Q value for a sphere represents a 0, while for a prolate ellipsoid this value has a negative sign and for an oblate one a positive sign. The average Q value of a normal human cornea is approximately -0.26, while the average Q of the SA of a 6mm optic zone is +0.27. The magnitude of total aberrations is called mean square (RMS). The quality of the image is estimated with parameters such as PSF (point spread function) [10]. In an ideal optical system PSF resembles a dot or a remote star. PSF can be mathematically converted into modulation transfer function (MTF), which facilitates the identification measurement of the total function of the eye. Thus, with MTF curve, the position of an optical or sensory deficiency can be pinpointed. The aberrations can be divided into chromatic and monochromatic [1,10]. The former are contingent to the wavelength of the light that goes through the eyes. Chromatic aberrations cannot be corrected or measured, given that they are regulated by the composition of the ophthalmic structure. Accommodation is vital in the creation of aberrations. The greater the accommodation is, the more monochromatic aberrations increase [1]. The employment of aberrometers for the measurement of the aberrations of the visual system is essential in conducting the main refractive surgeries, such as PRK and LASIK. Wavefront sensors in eyes with a high degree of ametropy cannot conduct accurate measurements due to the overlapping of spots, so the measurement of aberrations is based on the exact position of a collection of spot images [10]. It has also been substantiated that irregularities in the tear film are associated with dry eye, thus increasing HOAs [11]. What is more, the individual healing response to the laser ablation is of considerable importance [12]. In cases of eyes with immature cataract HOAs may be affected, leading to inaccurate estimations of aberrations [13]. The number of spots analysed by each device is not the same. Spherical aberrations, coma and astigmatism commonly influence visual function.

The quality of vision is highly dependent on HOAs, despite the latter constituting less than 10% of the total aberrations of the eye. What led to further study of the issue of aberrations was the induction of aberrations with the use of conventional refractive surgery [2,5]. This means that it is steeper in the centre and more flat in the periphery. This is because standard refractive surgery introduces SA, given that it converts prolate cornea to ablate, increasing the glare and hale symptoms, which ultimately leads to reduced optical conception. Additionally, it disregards the sphericity on the surface of the cornea, since the ablation used to be calibrated on flat surfaces, which led to inadequate ablation in the periphery of the cornea [1,6].

Therefore, we were led to the discovery of ways to ameliorate the refractive effect. For example aspherical therapies in the form of prolate laser ablation lessened the total amount of aspherical aberrations of the eye, especially with patients older than 40 years old. Therefore, the aim was to maintain or increase the natural prolate shape of the cornea, which in its natural state is a prolate ellipsoid of 3 dimensions. As a result, therapeutic modes should aim at the reduction of inducing high level spherical aberrations, which is achieved with the use of customized ablations [14].

Methods of literature research

Publications in electronic databases until 2021 (pubmed, medline and Elsevier Science) were searched. The following keywords were used Lasik, PRK, Wavefront-optimized (WFO), Wavefront guided (WFG), high-order aberrations (HOAs), smile (small-incision lenticule extraction), Hartmann-Shack, Tscherning, i-Design, subjective measurements, QoV, questionnaires for refractive error.

Aspheric therapies

Customised treatments aim to ameliorate the “radial compensation function”, so that the energy delivered in the periphery of the cornea can be adequate for the tissue to be removed. The size of the optical zone can ideally be increased in astigmatic treatments. A smoother central optical zone can be achieved, which is related to vision quality. Finally, eye trackers that rate torsional, as well as saccadic movements of the eye should be introduced [1]. Therefore, the changes in asphericity of the cornea can explain the induction of spherical aberrations, which are higher in cases of high myopia. Roberts [15] have also theorized an alternative mechanism of introducing ablations, which concerns the biomechanical response of the cornea. According to Yoon [16], the diverse ablation depth and biological response of the cornea accounts for 50% of the discrepancy in the spherical aberrations introduced.

Hartmannn-Shach is an outgoing wavefront-aberrometer, that is, it defines the form of the wavefront which emerges from the eye. A point of light source is placed in the fovea, intercepting the emerging wavefront [10,17]. An arrangement of microscopic lens subdivides the outcoming wavefront into multiple beans, which focus on the sensor that receives the array of the spot images. In the optical system each individual lens intercepts parts of the aberrated wavefront that is deviated from the lenslet axis. The position of the light spot will be shifted due to the deviation of the wavefront. Thus, we receive a distorted network of light spots. By comparing the deviation of the positions of the light spots between the aberrated and optimal wavefront, the pattern of the wavefront can be reconstructed. Therefore the device measures the deviations of each spot from the equivalent corresponding reference point [10,17]. Ingoing aberrometers constitute an alternative type that is, Tscherning aberrometers in which an aligned beam of rays penetrates a mask with the regular pattern of pinholes. In Tscherning system the eye is converted into a myopic one with the use of a positive lens, therefore the beam focuses in front of the retina and then expands before reaching the retina. As a result, a shadow of mask is formed in the retina. Ophthalmic aberrations disrupt the light frame as the latter enters the eye, thus causing disturbance in the projected grid. The aberrated retinal grid pattern is compared to the ideal grid, eventually forming the aberrations map [10,18].

All wavefront sensors measure the total wavefront errors, while the cornea aberrations are estimated through the topographic data. There are two commercially available aberrometers, the Hartmann -Shack and the ones of Tscherning type. As regards the low-order aberrations, there is unanimity concerning the values of aberrations received by the various aberrometers, of which the most advanced is the i-Design that analyses 1250 points [5]. The outcomes of the use of i-Design were significant in, for instance, the correction of astigmatism 1 month post-operatively as was measured by vector analysis and there was a high degree of satisfaction on the patients’ part [20].

Disturbances in vision were attributed to small therapeutic zones and post-surgery astigmatism. The achievement of enhanced visual acuity is the main objective [21]. Wavefront-optimized profile favours the maintenance of pre-existing optical aberrations [22]. According to Smadja [23] in a wavefront-optimized ablation, an increase in the total HOAs was observed. However, statistical significance was apparent only in cases of moderate and high myopia. Spherical aberrations are the ones that display increase following a myopic ablation in moderate and high myopia. Conversely, in low myopia cases, the induction degree of spherical aberrations stood at 0 and obviously there was no statistical significance. As for coma, the change in RMS coma was statistically significant in high myopias. A further vital feature in the quality of vision is eccentricity. In conditions of moderate and high myopia there was a statistically significant reduction in eccentricity, that is, a shift of the cornea to a more oblate shape. The conclusion that Smadja [23] reaches is that there is a profound induction of spherical aberrations in ablation regarding cases of myopia exceeding 6D in the optical zone of 6mm. According to Bottos [24] there is positive modification in cornea asphericity in myopic ablation, while negative modification is reported in hypermetropic ablation. Also, the reason behind a potential unpredictable post-lasik asphericity lies in biomechanical properties of the eye. The shift in corneal shape may affect the visual outcome, regardless of the full correction of refractive errors. Therefore, there is poorer image quality with emerging symptoms of double vision, halos and starbursts. Decentration can also affect the quality of vision owing to subclinical ablation [25].

High-order aberrations (HOAs) effects

SA and coma bring about the majority of the symptoms following refractive surgery [4]. Regarding eyes with significant disturbance of night vision and positive spherical aberrations > 0.50 μm produced by previous operations for myopia correction, there was presented considerable improvement in night vision with reduced cornea SA when WF guided customization with aspheric profile was applied [26]. Despite the fact that the treatment targeted SA, the cure of other cornea aberrations finally ameliorated night vision. In treatments for the correction of aberrated corneas there was a great improvement in UCVA of two lines [27]. All patients showed improvement in visual acuity, diplopia and night vision, which is also inferred from the better PSF [28]. Wavefront-guided LASIK enhancement using the Schwind eye-tech solutions for previous decentered refractive surgery proved the safe and effective correction of 2^{nd}-order components. Additionally, coma was considerably decreased and symptoms of night vision also declined as, in the case of decentered ablation, there is difficulty in night vision, given that the pupil dilates [28].

Wavefront-optimized ablation profiles are based on the premise of the maintenance of a more prolate corneal shape, along with the reduction in the induction of spherical aberrations. This laser increases pulse energy in the periphery, so as to avoid cosine effect. For patients with a low degree of HOAS (< 0.35 over a 6,00 mm pupil), the outcomes of optimized profile and wavefront profile were similar [29]. However, in eyes with RMS > 0.35 over a 6 mm pupil the outcomes with wavefront guided profile were better [30,31]. In cases of wavefront guided ablations the symptoms of night driving were ameliorated and there was also reduction in glare and halos, as well as better contrast sensitivity [32]. Wavefront treatments, though, require centration, fixation and correction in cyclotorsion. What appears to be essential in Wavefront-guided ablations is the lessening in the introduction of new wavefront errors, rather than the reduction in the preexisting aberrations. Regarding highly ammetropic eyes (with decentered ablations, small optical zone or irregular astigmatism), there is apparent benefit from topographic -guided treatments [33].

SMILE is another refractive procedure in which a refractive lenticule using a femtosecond laser is removed from the eye through a small incision. Comparing small-incision lenticule extraction (SMILE, RELEX, Carl Zeiss, Meditec AG) and Laser *in situ* keratomileusis (LASIK), both techniques are equally safe, effective and predictable as concerns moderate myopia and astigmatism [34]. However, dry eye was not as frequent in lasik as in SMILE.

Vision related quality of vision and quality of life

Apart from the evaluation of optical and refractive results through wavefront-guided lasik, the estimation of vision-related quality of life is also of considerable interest.

The level of patients' satisfaction one year after binocular wavefront-guided LASK is high. Functional vision and quality of life related to optical activities presented total amelioration following wavefront-guided LASIK. This is accomplished with the use of high-order aberrometers.

The refractive status and vision profile (RSVP) [35] questionnaire was developed for the evaluation of optical symptoms and outcomes, in daily functions and quality of life. RSVP questionnaire was used, via which there was assessment of total vision related quality of life for patients in the period of 1 month to 1 year after surgery [36]. It was only with the symptoms such as sensitivity to light, pain, glare and low-night vision that RSVP scores declined in the first month after surgery. Within the first post-operative months symptoms of dry eye, glare halos and night driving vision had been eliminated. By the twelfth month, however, the scores had improved. In the period of 12 months problems with driving in rain, glare and oncoming headlights were alleviated, reaching over preoperative levels. Higher average trefoil and RMS error of 0.3 μm or more leads to a great average of dissatisfaction 12 months post-operatively [36]. The patient-reported outcomes with laser *in situ* keratomileusis (PROWL) studies showed 96-98% satisfaction after LASIK [37].

Additionally, there was employment of the Quality of vision (QoV) questionnaire by Kung and Manche [38], while comparing WFG Lasik and WFO Lasik. Regarding individual symptoms there were no differences found between the two platforms. However, patients tended to show preference for WFG LASIK and those with RMS < 0.3 reported better vision.

Using the Quality of Life impact of Refractive Correction (QIRC), questionnaire which was developed using Rasch analysis models, femtosecond laser and wavefront-guided ablation accounts for improved results in visual function and symptoms questions due to less induced astigmatism and fewer HOAs [39,40].

When comparing visual -related quality of life after smile and lasik, results were similar. In a review comparing patient-reported outcomes of Lasik and smile when using QIRC questionnaire, results were similar regarding the above procedures 3 months post-surgery [41,42].

Recent advances in wavefront devices

The presence of various aberrations in the eye can affect the light path. Therefore, observing where the light returns in relation to the cornea, enables the prediction of the cornea shape, which is necessary in full focus.

The i-Design Advanced Wavescan is a newly developed high resolution aberrometer. According to Moussa., *et al*. [43] there was considerable reduction in the total RMS, as well as in the level of spherical aberrations 2 months following operation, using the i-Design and Visxstar 4S system, which signifies that not only was there limited induction of aberrations but also elimination of them to a certain extent. The results were also far better in cases of high myopia when the i-Design and Visxstar 4S platform was used [44]. Comparing the Visx custom-Vue to the Allegretto report improved predictability, reduced HOAs and better reported clarity, especially for patients with RMS > 0.3 [45].

Correlating SMILE method and the WFO LASIK Khalifa., *et al*. [46,47] showed more favorable results when Visx/iDesign high revolution aberrometer is used. Also, they report more limited induction of HOAs and more predictable cylinder correction in WF-G LASIK, which is probably attributed to other factors such as axial or torsional registration, as well as improved centralisation due to the centroid shift and greater energy transfer in the mid periphery of the cornea. Additionally, the comparison of topography guided LASIK (OPD scan with the EC -5000 CXII Nidek) revealed that some subjective symptoms related to QoV were milder in the WFG-LASIK group. In another study comparing Visx-IDesign and ALCON -CONTOUR (topography guided platform) and Nidek IAI3, to ALCON Contoura displayed better results in high degree aberrated corneas which signifies that topography -guided ablations may outperform others in such eyes[48]. In the comparison of post-operative astigmatism using vector analysis results with the use of WFG and SMILE (VISUMAX), the results of the former were better.

Conclusion

What is the optimum profile for a patient?

Decision trees can aid in the improvement of clinical results. A decision tree is identified as the most likely option among others. Each possible alternative is known as decision option, while a decision node signifies the most favourable option among the rest. The direction followed is mainly from left to right, with this course of chance nodes followings the sequence of events over time [51].

The first decision tree was designed by Theo Seiler., *et al*. [52] was based on clinical observations, as well as on the remarks of the users of excimer laser. According to that decision tree, wavefront optimized treatment is a suitable choice, when optical acuity is proper (> 20/20) and when there is good night vision and sound quality of vision. In cases measured aberrations show an outcome of RMS being > 0.4 then the wavefront-guided treatment is recommended, rather than wavefront-optimized one.

The shift to wavefront-optimized profile was detrimental because after the use of conventional ablation there was increase in refractive reflectivity in the periphery, due to an extended angle of the beam, which brought about energy loss of up to 80%. By using customized ablation there was a wider optical zone and greater peripheral blend zone. Furthermore, the ovalization of the beam in the periphery resulted in a wider area of energy dispersal, for an equal amount of energy. It is essential, therefore, that the appropriate type of ablation profile take into account the curved corneal surface, so as to avoid sub-corrections in the periphery, which was a common place phenomenon, known as "cosine effect" [49].

Patients are capable of distinguishing the difference between optical results. Schallhorn., *et al*. [50] reports patients, with vision outcomes, as well as satisfaction with vision, even 5 years after LASIK. He reckons that UCDA was the best indicator of satisfaction and that optical recovery was significant in vision satisfaction.

Stonecipher *et al*. [49] found a UCVA better than 20/20 which can be achieved on the first post-operative day, using a decision tree which helps the surgeon in choosing the best treatment profile. In this study a decision tree was developed regarding choices of Wavelight Allegretto and FS 200 femtosecond laser in relation to Wavefront -guided using the Visx custom platform with Intralase. There are different studies which compare ablation profiles. More of these studies brought out similar clinical outcomes between groups [31].

With wavefront optimized ablation there is minimal induction of HOAs for treatments up to 6D, so with the reduction in aberration inductions there is improvement in the quality of vision when the size of the pupil increases. Therefore, glare is minimized and optical acuity in the dim light is reduced as well [52]. WF guided profile is more complicated since it requires precise adjustment and registration of the eye at the time of measurement and treatment. Finally, there is also topographic profile (custom contour ablation pattern), which has been designed for the correction of irregular astigmatism in eyes that had been previously been operated on and displayed decentration. These treatments are not contingent on the pupil but on the fixing point. The measurement zone is wide, allowing the evaluation of peripheral irregularities of the cornea [48].

What ought to be mentioned is that with wavefront- guided LASIK there is customized ablation achieved, which is personalized for each patient, taking into consideration the total structure of the eye. Therefore, the best possible vision is desired rather than supervision of 20/10 or higher.

In conclusion, the available literature suggests that LASIK and SMILE do not differ regarding subjective outcomes and patient satisfaction. There is some evidence that after SMILE there might be a better vision-related quality of life However, more studies are needed to extract conclusions as regards vision-related quality of life in the late postoperative period [54-56].

Disclosure

I declare no financial interest or any conflict of interest.

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Volume 13 Issue 8 August 2022
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